Heat Stress in Firefighters Wearing Level 3 Chemical Protective Suits

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SUMMARY

Emergency workers during training or real rescue situations can be exposed to excessive heat. This heat exposure can cause significant physiological changes and adversely effect the body. And any protective clothing that is worn can greatly enhance the effect of heat on the body by impeding the body's cooling mechanisms.

The study (1), condensed in this paper, was performed to evaluate the effects of heat on firefighters during training sessions while wearing Trelleborg Trellchem fully encapsulated chemical protective suits. The firefighters were exposed to three air temperatures (30°C, 35°C and 40°C). During each exposure their heart rate and body temperature was continuously monitored. Blood pressure and fluid loss was measured before and after each heat exposure. And recovery rates were measured to evaluate the effects of high air temperature on the body.

Twenty (20) firefighters participated in the study. The study indicated that short periods of exposure to heat caused significant changes in body temperature, heart rate and blood pressure. Also the heat exposure had a significant effect on the rates of recovery.

INTRODUCTION

Firefighters often perform strenuous work in hot conditions which can cause heat related illnesses. The working conditions impose physical and mental strain on firefighters. This strain is due to the interactive effect of a heavy workload and thermal stress. The workload is created by the level of activity and the equipment used such as heavy protective clothing and breathing apparatus. And the thermal stress is generated from both the external heat produced by a fire and/or the sun, and the heat which is produced internally from a combination of metabolism and the inability of the body to dissipate heat in extreme thermal conditions. This buildup of body heat leads to fatigue, behavioural changes, exhaustion, heat stress and in extreme cases, death.

During any activity, the body attempts automatically to maintain a constant working temperature range by balancing body produced heat and heat gained through the environment with heat loss (2, 3, 4). Normal body "core" temperature occurs between 36.7°C and 37.0°C (5). Heat balance is achieved when the net heat gains are equal to the net heat losses. When the body gains heat through metabolism or the environment, various physiological mechanisms are activated to dissipate the heat to maintain this balance. This includes the activation of the sweating reflex and the dilation of cutaneous blood vessels. As the blood vessels dilate, the skin vasculature becomes swollen with warm blood, permitting heat loss from the skin by cooling mechanisms such as conduction, convection, radiation and/or evaporation of sweat (5).

However when the environmental conditions are hotter than normal body temperature, the effect of cooling by conduction, convection and radiation is impeded. Such conditions include high air temperature, high humidity, high radiant heat and low airflow. In this situation the evaporation of sweat is vital in cooling the body (4, 6, 7). Although, when the air reaches 100% relative humidity, the ability of the air to evaporate any more moisture is greatly reduced. Therefore the body loses the ability to dissipate heat through the evaporation of sweat. When this occurs the body gains heat rapidly and as a result heat related illnesses may occur. Heat illnesses affect individuals in different way, but generally such illness is characterised by an increase in core body temperature, loss of fluid through sweating and a substantial increase in heart rate.

BACKGROUND TO THE PROBLEM

The Queensland Fire Service (QFS) firefighters wear a chemical protective suit to chemical emergencies. The suits are fully encapsulated with breathing apparatus worn inside. They are worn for a maximum of 20 minutes, based on breathing apparatus capacity.

The suit is designed to protect the firefighter from the hazardous environment. However in doing so, the suit creates a thermally hostile environment around the firefighters. The sources of heat come from the sun, radiant heat from road surfaces for example and the buildup of metabolic heat generated by the body during activity. As the suit is designed to 'keep the nasties out', consequently nothing can escape from inside the suit. While working in the suit, heart rate increases, body temperature starts to rise and profuse sweating occurs to cool the body. However as this heat, moisture and respired air cannot escape, soon the humidity rises inside the suit and sweating becomes less effective in cooling the body.

The purpose of the study was to:

- Evaluate the effects of temperature (30°C, 35°C and 40°C) on heart rate, body temperature, blood pressure and fluid loss while performing work in Level 3 suits. (20 minutes only).

- Evaluate the effects of temperature (30°C, 35°C and 40°C) on the rates of recovery.

METHODOLOGY

The study involved human experimentation and the methodology was submitted to the QUT Ethics Committee for approval. Approval was also sought form the QFS management and union.

All research was performed at Roma Street Fire Station, making use of the heat training facility.

Information sessions were delivered to A, B, C & D shifts of Roma St Fire Station to call for volunteers for the research. A huge response was received and 20 firefighters volunteered to participate in the study.

A consent form was signed by each subject prior to the commencement of the study. The form outlined the possible risks of the heat sessions and giving the option to the subjects to withdraw from the study at any time due to any reason.

The subjects participated in a fitness assessment and three heat sessions at 30°C, 35°C and 40°C. These are described below.

Fitness Assessment

A battery of tests were performed to obtain baseline data on subjects' fitness. The following were included: height, weight, blood pressure, lung function and cardiovascular fitness.

Heat sessions

Each subject performed three heat sessions (30°C, 35°C and 40°C). Each heat session being the same, the only difference being a change in temperature. All subjects were declared to be fit on the day, no flu etc. Heart rate, body "ear" temperature, blood pressure and weight was measured in each session. The heat sessions were divided into three phases.

(1) Phase one (pre-exercise) - the subject was seated and the heart rate monitor (PE2000 Polar Sports Tester) and body temperature monitor (Questemp°II - ear temperature) was fitted to the subject. Both instruments are data logging facilities. Pre-exercise levels were measured. During this phase, time was provided for questions etc. Blood pressure and weight was also measured. Once all equipment was fitted to the subject, the subject put on the breathing apparatus (BA) and suited. All procedures were timed to identify with the monitoring equipment timing mechanisms.

(2) Phase two started when the subject entered the hot room and began work. The work task involved transferring 15L drums of water from one table to another for the time in the hot room. Each subject worked at their own pace, maintaining this rate for each session. This was to ensure that any changes in heart rate could be accounted to the effect of heat and not an increased level of activity.

After 20 minutes duration in the suit the subject was undressed and BA removed.

(3) Phase three - recovery phase. Blood pressure was taken as soon as one arm was free from the suit. The subject was then taken to the recovery room. The room was kept at a constant 25°C for each recovery session. Heart rate, body temperature and blood pressure was monitored until returning to pre-exercise levels as much as possible. In some cases the subjects were not fully recovered as they were on call. Another weight measurement was taken to determine any weight difference due to sweating. On completion of session the subject was advised to replenish lost fluid.

Each subjects heat session was at least one week apart to allow full recovery and reduce the effects of possible acclimatisation.

All data was retrieved from the instruments. Heart rate, body temperature, blood pressure and fluid loss was then compared between the three sessions to evaluate what the effect of heat had on these parameters. An analysis of variance (ANOVO) was used to evaluate the differences between these.

RESULTS

A condensed version of the results is presented with overall findings. Fitness assessment results are not presented.

Heart Rate

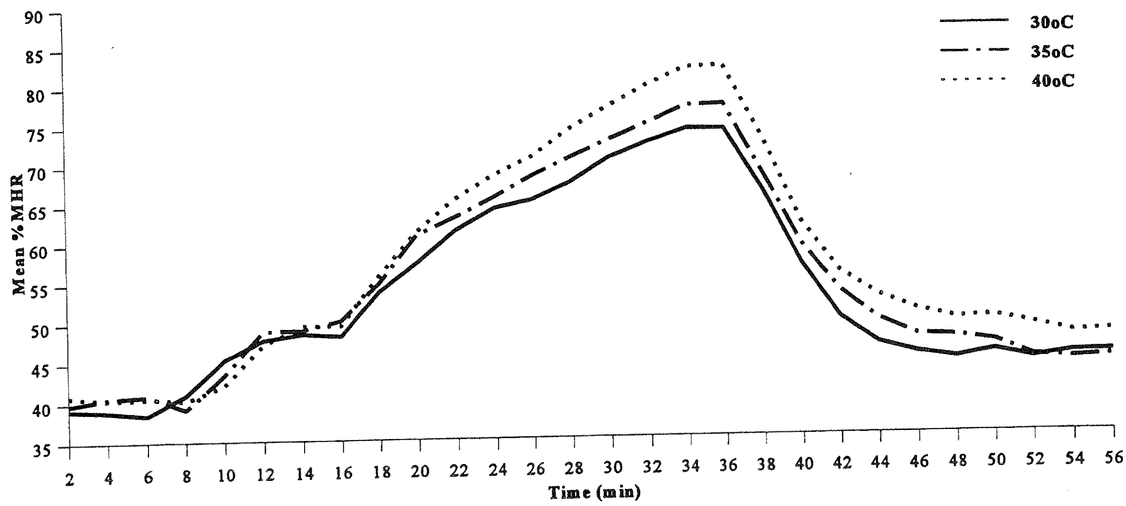
All heart rate data was examined as a percentage of the subjects' maximum heart rate (%MHR) to eliminate the effects of age. As a general rule when a person ages, their maximum heart rate decreases. MHR is calculated by the following equation, MHR = 220 - age (2).

Figure 1 represents the mean %MHR data over the three heat sessions. The heart rate levels were relatively the same during phase one. Heart rate started to increase rapidly when the subjects were exposed to the hot working conditions. And then when the subjects were removed from the conditions, heart rate dropped quickly.

The heart rate data was divided into the three phases for analysis. The analysis showed before any exposure to heat the heart rate levels remained the same. In phase two the total rise in %MHR, average increase in %MHR every 2 minutes and highest %MHR reached was analysed. Each showed significant results between the temperatures. The overall analysis indicated that when the temperature increased the heart rate significantly increased. The rate at which heart rate returned to pre-exercise levels was also analysed. The analysis found that when the subjects were exposed to a higher temperature their recovery took longer.

The mean highest %MHR for 30°C was 75.5% of MHR, at 35°C was 78.8% of MHR and at 40°C was 82.6% of MHR. Some subjects were working at 90% of their MHR for several minutes which is alarming.

Figure 1: Graph of Mean %MHR of subjects over the three heat session (Phase 2 starts at the 16th minute, Phase 3 starts at the 36th minute)

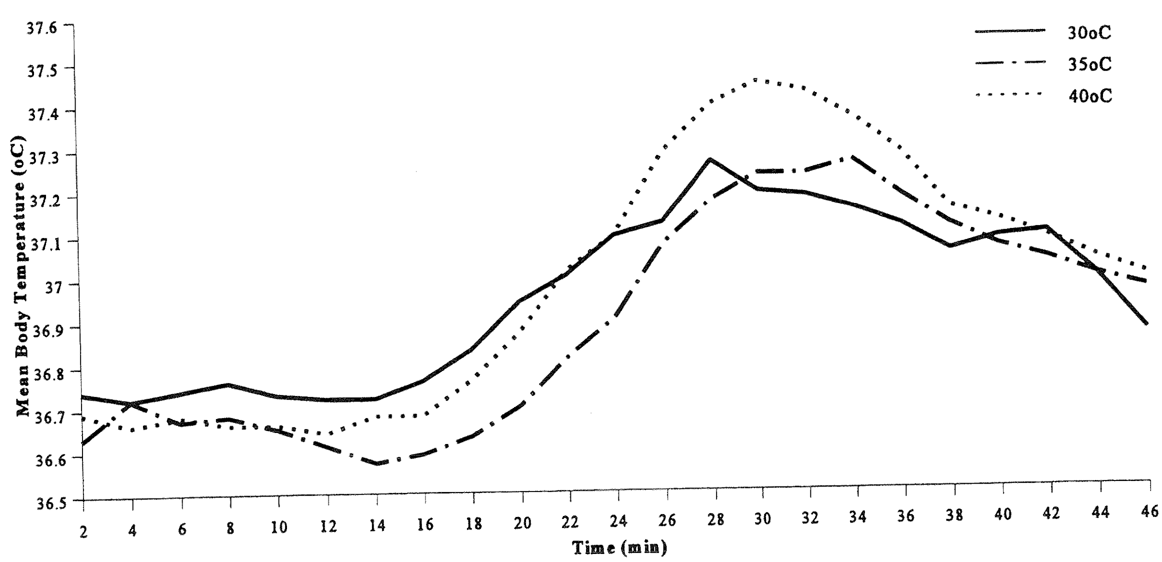


Body Temperature

Figure 2 presents the mean body temperature data for the three heat sessions. As with heart rate, body temperature exhibited a rise when exposed to the heat and declines when removed from the hot working conditions. As each subject started at a different body temperature, the total increase in body temperature was analysed. The analysis indicate that the increase in body temperature between the heat sessions was significant. The mean increase in temperature above normal body temperature in the 20 minute heat session was:

- 0.84°C at the 30°C heat session,
- 0.91°C the 35°C heat session, and
- 1.06°C at the 40°C heat session.

Figure 2: Graph of Mean Body Temperature over heat sessions (Phase 2 starts at the 14th minute, Phase 3 starts at the 34th minute)



Blood Pressure

The systolic and diastolic blood pressure was measured before any heat exposure, no significant differences were found between the sessions. All blood pressure analyses showed that as the temperature increased, systolic and diastolic blood pressure also increased. This increase was more significant at the 40°C heat session. Recovery of blood pressure to normal levels took longer as the temperature of the heat session was increased. At the 30°C heat session, blood pressure required a mean time of 14 minutes to recover, 18 minutes for the 35°C heat session and 24 minutes for the 40°C heat session.

Fluid Loss

Fluid loss analysis indicated that there was no differences between the three temperatures. The amount of fluid lost through sweating is a highly individual trait. The greatest amount of fluid lost by a subject in the 20 minute period inside the suit was 1.1L and least was 0.2L.

DISCUSSION

Heart Rate, Body Temperature and Blood Pressure

Overall analysis indicated that heart rate, body temperature and blood pressure will increase while working in a hot environment, as supported by many authors.

There was a progressive increase in heart rate until each subject was removed from the heat. This suggests that if more than 20 minutes was spent in the suit, heart rate would continue to rise. For some subjects this would not cause an immediate problem, however some subjects were working at 90% of their MHR at the 40°C heat session. High %MHR levels cause considerable strain on the heart and lead to adverse cardiovascular consequences.

The combination of exercising muscle and the gain of metabolic and environmental heat causes a considerable increase in heart rate. A majority of the subjects were working at high heart rate levels in this study's controlled working situation. It is expected that in a real emergency, heart rate will be starting at a higher level due to a large discharge of the sympathetic nervous system (flight or fright response). This will cause firefighters to work at more extreme heart rates for longer periods of time. It would be ideal to monitor heart rates in an emergency situation, however the results in this study can now be used as a base guideline for heart rates in such a situation. This, of course, depends on the temperature exposure and level of activity involved in the emergency. As a general rule, as the temperature and level of activity increases, the heart rate levels can also be expected to increase.

At the 40°C heat session, heat rate, blood pressure and body temperature reached significantly higher levels than the other sessions. This is due to the air temperature being higher than normal body temperature, forcing the body to gain and store heat. This heat gain increases body temperature and the heart works a lot harder to pump blood to periphery for heat loss, giving the rise in heart rate and blood pressure.

Maintaining a level of fitness and heat acclimatisation will improve an individuals performance in the heat, although this will not prevent heat stress from occurring. The introduction of training programs to enhance fitness and heat acclimatisation should lower heart rates and produce better performances in a hot environment. An increased fitness will enable work to be performed at a lower heart rate. This allows for an aerobic reserve for further rises in heart rate if faced with increased work demands. This sudden increase in work demands is characteristic for emergency service personnel.

Fluid Loss

Regardless of the insignificance of the fluid loss analysis, hydration is very important when working in a hot environment. A reduction in hydration level can interrupt normal physiological functioning. Failure to replenish fluid after exercise, and more so in the heat, results in a feeling of lethargy and some instances dizziness.

CONCLUSIONS

Firefighters exposed to heat during training experienced significant changes in body temperature, heart rate and blood pressure. The magnitude of these changes was due to the combined effects of exercise in high temperatures, 100% relative humidity and the reduction of cooling created by the thermally hostile environment inside the suit. These significant changes were observed after an exposure of 20 minutes.

Effective firefighting requires high performance for unpredictable periods in intense heat, and under time constraints due to working time in breathing apparatus and protective clothing. These conditions are detrimental to a firefighter's health. Regular physical activity and also training in the heat are seen as advantageous to improve a firefighters work capacity and energy reserves in a heat stress environment.

While there is still a need for studies in heat stress in emergency service personnel, especially in Australia, this study found that the subjects were performing work at near maximal heart rates for sustained periods accompanying an increase in body temperature and often substantial fluid was lost. This is supported by overseas studies and the available information on the physiological effects of heat and heat stress in emergency service personnel. The findings of the research have practical applications in refining operational and training procedures to reduce possible adverse health effects for personnel working in hot environments. Similar research is now proposed with the Mines Rescue Brigade.

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